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The Greenhouse Effect and Climatic Change

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THE GREENHOUSE EFFECT AND CLIMATIC CHANGE

ISSUE DEFINITION

Over the last quarter-century, scientists have conclusively demonstrated that the amount of carbon dioxide (CO_2), the dominant gas that contributes to the greenhouse effect, is increasing in the atmosphere. A rise of about 4% in CO_2 concentration during the 1970s alone and of 8% over the last 25 years has been measured; an increase of some 20-30% since the beginning of the Industrial Revolution is inferred. What this environmental shift may mean for man and his planet has been, until recently, a matter of controversy.

The greenhouse theory holds that adding large quantities of carbon dioxide, and just as importantly, other trace gases, to the atmosphere will warm the earth. Most climatologists now believe that the higher concentrations of these gases will induce a global warming sufficient to cause extensive change in climatic patterns. Climatic change is a matter of great import to global agriculture, especially in developing countries where the agricultural system operates under marginal climatic conditions. A warming planet and consequently rising sea level could eventually also have a far-reaching impact on man's patterns of habitation.

BACKGROUND AND ANALYSIS

It may seem odd to think of CO_2 as a pollutant because it is a natural and essential component of our atmosphere, but it is not the gas <u>per se</u> which is the problem; it is rather its rising atmospheric

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concentration resulting from the combustion of increasing quantities of fossil fuels and perhaps because of deforestation, which is potentially environmentally disruptive. The earth's global mean temperature has remained remarkably stable over the millenia (probably varying by only some 6°C between the glacial and interglacial extremes of the last 20,000 years), but by pumping CO_2 and other trace gases into the air at an increasing rate man may be setting the stage for a large excursion from the climate he thinks of as "normal."

A. The Relationship between Atmospheric CO_2 and Climate

The earth receives radiant energy from the sun but it must reradiate that energy back into space or our world would become progressively hotter. Solar energy arrives at the earth's surface at wavelengths lying predominantly within the visible part of the electromagnetic spectrum. The earth reradiates energy, however, at longer wavelengths which concentrate in the far infrared or "heat" end of that spectrum. The energy of these longer wavelengths is more readily absorbed by naturally occurring CO_2 and water vapour in addition to other infrared-absorbing gases such as nitrous oxide, methane, chlorofluorocarbons and ozone. This absorption occurs primarily in the troposphere, the region from the earth's surface up to an altitude of 10 to 15 km.

When these molecules absorb energy, they cause general atmospheric warming, a phenomenon commonly called the "greenhouse effect" because it is crudely analogous to the warming of a glassed enclosure. These gases thus act like a "thermal blanket" around the earth, and as their atmospheric concentration increases, and the absorption of energy in the infrared with it, incoming radiation temporarily exceeds outgoing radiation. The temperature of the atmosphere rises and a new radiation balance is established.

Most estimates of the increase in the mean global temperature of the lower atmosphere which could result from a doubling of the present CO_2 concentration lie between 1.5° and 4.5°C. The most recent

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and more complex models used to predict these changes now narrow this range to between 3.5° C. and 4.2°C. In addition to CO_2, if current trends of increases in the concentrations of other trace gases continue, a global climate warming equivalent to that expected from doubling the CO_2 concentration in the atmosphere could occur as early as the year 2030. This increase is not expected to occur evenly over the earth's surface but to be much more pronounced towards the poles.

B. Sources of Carbon Dioxide (Fossil Fuels and Deforestation)

Carbon dioxide is the vehicle which transports carbon through the carbon cycle. It is removed from the air by plants during photosynthesis to make solid organic compounds, and when these compounds are respired, CO_2 is again released to the atmosphere. Carbon dioxide dissolves in the oceans as bicarbonate and can be converted to the solid, calcium carbonate, by shellfish. In the very long-term, CO_2 can be converted to fossil fuels. Thus, carbon dioxide is part of the cycle of carbon circulation (a biogeochemical cycle) which consists of both living and nonliving components.

The pollution potential of CO_2 is a function of its low atmospheric concentration. Whereas nitrogen composes about 78% of the atmosphere by volume and oxygen 21%, carbon dioxide comprises only slightly more than 0.03%. Therefore, only a relatively small addition of CO_2 to the air is needed to change significantly its global concentration. The atmospheric concentration of CO_2 has varied over geological time. Nonetheless, in mankind's recent history there is believed to have been an approximate balance in the exchange of carbon between the atmosphere and terrestrial biota (plant and animal life), and between the atmosphere and the oceans. Industrial man has caused a small but increasingly significant alteration in this natural carbon cycle.

Over the last half-billion years of our planet's more than 4.5-billion-year history, a small percentage of the carbon circulating through the earth's surface environment has been diverted and stored in sedimentary rocks as fossil fuels. Industrial man, however, seems intent

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on returning to the atmosphere within a century or two a significant fraction of the carbon which nature has accumulated in fossil fuels over many millions of years.

Fossil fuel combustion has released an estimated 160 billion tonnes of carbon to the atmosphere since 1900, with the present contribution calculated to be approximately 5 billion tonnes annually. Future levels of emissions are conjectural, depending upon the assumptions one makes regarding population growth, technological change, the global economy, energy conservation, fuel costs and the evolution in the mix of energy sources which satisfy man's energy requirements.

Since terrestrial biota and soils contain roughly three times as much carbon as the atmosphere, their alteration can add or subtract CO_2 to the atmosphere. When man harvests the world's forest resources without provision for their regeneration, as is occurring today in many regions of the earth, he adds to the atmospheric CO_2 pollution problem because (a) the trees which are felled are no longer able to photosynthesize and remove CO_2 from the air; (b) this biomass releases CO_2 when it is burned or when it decomposes; and (c) harvesting the forests bares the soil's surface and exposes it to the forces of erosion. As decomposition of the humus content of the soil progresses, even more CO_2 is released to the atmosphere.

No one knows with any certainty how much CO_2 is entering the air as a result of deforestation. The prevailing view is that deforestation can be a substantial contributor to atmospheric CO_2 over comparatively short periods of time, and since some 40% of all plant carbon is stored in tropical rainforests such as those of the Amazon basin, extensive clearing of these forests would undoubtedly release huge amounts of CO_2. Estimates suggest deforestation contributes from 0.9 to 1.2 billion tonnes CO_2 annually (i.e. one fifth the amount input by fossil fuels.)

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C. Sinks of Carbon Dioxide (Vegetation and Oceans)

Measurements suggest that only about half of the total amount of anthropogenic CO_2 produced over the last century has actually stayed in the atmosphere; CO_2 must be absorbed or stored somewhere or the atmospheric concentration would be greater than observed.

Introducing new crops into previously unsuitable climatic zones and fertilizing plants to stimulate growth may well be countering much of the carbon loss due to deforestation and land disturbance. There is some evidence to suggest that the rising concentration of CO_2 in the air is stimulating plant growth, enhancing the carbon retention capacity of the world's vegetation. On the other hand, higher temperatures tend to increase plant respiration which releases CO_2. In short, aside from deforestation, the extent to which and under what circumstances the earth's vegetation acts as a net contributor or recipient of atmospheric carbon remains to be resolved.

The oceans of the world contain substantially more carbon than the atmosphere, the biota and fossil fuels combined. Although much remains to be determined about how the oceans and the atmosphere exchange carbon dioxide, current research suggests that the oceans are absorbing about 40%, or 2 billion tonnes annually, of the carbon being added to the atmosphere by fossil fuel combustion.

The amount of CO_2 which can be taken up by saltwater depends not only on the chemical nature of the water's dissolved materials and its temperature, but also to a great extent upon the effectiveness of ocean mixing. Mixing is particularly important because it is only surface waters which are in contact with the atmosphere and which can readily absorb CO_2. Research has indicated that the rate of turnover of the ocean's thermally stratified waters is extremely slow. Only the upper 75 metres or so of ocean water has annual contact with the atmosphere while the average circulation time for the deep oceans is about 500 years. If surface waters become saturated with carbon dioxide, then the removal of accumulated atmospheric CO_2 could take an amount of time in the order of centuries.

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Furthermore, rising air temperatures will warm the upper layers of the oceans, reducing their ability to absorb CO_2. It is even possible and has been frequently suggested that the cooler waters, now the major CO_2 sink, could release CO_2 as they warm.

As studies and theories concerning the greenhouse effect evolve, it is becoming increasingly obvious that a holistic approach to ecological understanding and management is needed. For example, it is possible that, as shallow surface waters become more acidic due to acid rain and other anthropogenic sources, changes in the decomposition cycle of shells of planktonic molluscs will be brought about which could affect the CO_2 absorption capability of the oceans. As shells grow, they remove carbon from the shallow ocean layers and when they die they sink to greater ocean depths transferring their carbon in the form of $CaCO_3$ to these depths. In theory, this makes it easier for new atmospheric CO_2 to enter the upper ocean. Normally, in the North Pacific, these shells will dissolve best under the acidic conditions that are found at great depths, but areas have now been found where shells are dissolving in the top 10% of ocean depths because of the increased acidity. This of course returns carbon to this surface layer, reducing its capability to absorb atmospheric CO_2.

Recently, attention has focused on the world's river systems in the transfer of carbon from land to sea. In a major international study, more than 50 scientists around the globe are monitoring at least 50% of the freshwater discharge to the oceans. Preliminary results suggest that riverine systems may be a significant sink for carbon, especially in cases where dams have been constructed, impounding the sediment load in reservoirs. Once again one sees the hand of man modifying a natural biogeochemical cycle.

Still, balancing the equation of the carbon cycle is not possible using these carbon sinks alone and up to 50% more carbon than can be found accumulating in these sinks is unaccounted for. Although this imbalance has been suggested as reason to invalidate projections of the greenhouse effect, recent calculations may shed some new light on the equation and might contribute a new term to the global carbon balance,

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i.e. waste. Whenever waste is not somehow "recycled," but as in landfilling or dumping is essentially subtracted from natural cycles, its carbon content is segregated from the carbon cycle for many years. Preliminary calculations indicate 1.0 billion tonnes of carbon a year might be segregated in this way and the carbon balance should be modified accordingly.

D. Evidence of an Increase in Greenhouse Gases

1. Carbon Dioxide

Although the predicted after-effects of atmospheric carbon dioxide accumulation may be controversial, the recently-measured data are irrefutable. A number of scientific observers have concluded that over the period 1850 to 1980, the atmospheric concentration of carbon dioxide increased from perhaps 290 to 345 parts per million (ppm), although there is a growing body of opinion that the pre-industrial level may have been as low as about 250 ppm. More accurate measurements have shown that the concentration has risen 12 $\pm$ 1 ppm in the decade from 1970 to 1980 and has continued to rise by 1.0-1.5 ppm annually. Since the data suggest that there is some acceleration in the rate of increase in atmospheric CO_2 concentration, CO_2 levels may well rise to 400 ppm early in the next century.

Determining past atmospheric CO_2 levels is necessary to understand more fully how climatic change is linked to fluctuating CO_2 levels, systematic measuring having only begun in 1958. Analysis of CO_2 content in ice cores from Greenland and Antarctica, carbon in deep-sea sediments, and carbon isotopes in tree rings have all been used to determine the historic (pre-industrial revolution) CO_2 concentrations.

2. Trace Gases

Less abundant trace gases are now thought to contribute half as much to the greenhouse effect as does CO_2 at present, and as their concentrations increase, they are likely to have an effect on climate comparable with that of CO_2. Some of these trace gases have historically

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existed at lesser concentrations, (e.g., methane-CH_4; nitrous oxide-N_2O) while chlorofluorocarbons (CFCs), for example, have probably only existed in measurable concentrations since their synthesis by industrial society. Most of the attention has focused on the potential role of chlorine and bromine atoms of CFCs as ozone-destroying catalysts in the earth's stratosphere. Their effect as greenhouse gases in the troposphere has, however, also been recognized.

As discussed earlier, CO_2 and water vapour absorb the thermal radiation reflected back from the earth into the atmosphere within particular ranges of wavelengths. Interestingly, these gases have left open a "window" in the atmosphere (i.e. a particular range of wavelengths from 8 to 12 micrometres) where a substantial fraction of thermal radiation (heat) can still escape. Ironically, this atmospheric window is now being shut as all the trace gases in question absorb thermal radiation in this specific range of wavelengths. Can this window be left propped open given the production of trace gases to date and their expected future production?

Methane (CH_4) is at present the trace gas that, molecule for molecule, has the greatest greenhouse effect. The atmosphere now contains five billion tonnes, resulting in a concentration of approximately 1.6 ppm. The increase in methane, greater than 1% per year, apparently began in previous centuries and has doubled since the eighteenth century. Ice core dating indicates that its concentration was relatively constant for the previous 2,000 to 3,000 years. The sources of methane (the major component of natural gas) in the atmosphere and the reason for its increase is somewhat obscure although a recent examination lists rice paddies, ruminating animals (predominantly domestic cattle), biomass burning, swamps, and natural gas and coal mining losses as the major CH_4 sources, in decreasing order of importance. Since the residence time of CH_4 in the atmosphere is only 5 to 10 years, a reduction in its production could stabilize the atmospheric CH_4 concentration. However, this does not seem likely considering most of the sources of production. This matter is further complicated since the normal atmospheric removal process is being jeopardized by increasing concentrations of carbon monoxide (CO). Carbon monoxide destroys OH molecules that might normally remove methane.

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Nitrous oxide (N_2O) has been present in the atmosphere at stable concentrations for a long time and has recently shown an increase. If, as is likely the case, the N_2O increase witnessed recently (0.2% annually to 300 ppm) is due to either increased microbial activities associated with increased use of nitrogen-based fertilizers or an increase in the combustion of fossil fuels, then the imbalance is likely to grow rapidly unless major global changes in policy are made. N_2O has a residence time of over 100 years so reductions of input now would not be effective for some period of time. The contribution of N_2O to the greenhouse effect is approximately one-sixth that of CH_4.

The most common halocarbons are the chlorofluorocarbons (CFCs) CCl_2F_2 and CCl_3F which came into major production in the 1960s and were first measured in the atmosphere in 1971. Since then, measurements have shown that their atmospheric concentrations have grown at the same rate as would be expected based on industrial production. Global emissions of CFCs actually declined from the mid-1970s though 1982, but their long residence time - at least 100 years for CCl_2F_2 and 60 years for CCl_3F - leads to a continuing buildup; the average CFC concentration increased approximately 6% per year during the period when actual emissions declined. **Ratification of the 1987 Montreal Protocol to control the production of CFCs (signed by 24 nations) should reduce the future rate of CFC addition to the atmosphere.** CCl_2F_2 and CCl_3F are found at concentrations of 0.0003 ppm and 0.0002 ppm and are respectively one third and one fifth as effective greenhouse gases as methane. There are other halocarbons that are potential greenhouse gases which also should be controlled and phased out.

As noted earlier, the main concern for CFCs has been their effect in reducing the ozone layer of the stratosphere. The ozone layer shields the life forms of the earth from detrimentally high concentrations of ultraviolet light. Monitoring the ozone layer over the Antarctic since 1957 has shown the formation of a large, deepening hole in the ozone layer since the early 1970s. Since then, each year in the spring (October), the thinning of the ozone layer over the Antarctic has increased with an overall drop greater than 50% having been measured. **This hole in the ozone**

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layer is being interpreted as a manifestation of general stratospheric ozone depletion caused by CFCs, but intensified due to local climate conditions, a phenomenon extremely disturbing to the scientific community. (See the Library of Parliament publication "Ozone Depletion and the Montreal Protocol," MR-8, 29 September 1987, for further details concerning the CFC problem and the international efforts initiated to counter the depletion of ozone.)

E. Implications of Increased Atmospheric Levels of CO_2

Until recent media and political attention, most people were unconcerned when they heard that the earth's mean temperature could rise by between 1.5 and 4.5°C in response to a doubling of the atmospheric CO_2 level and increases in the other greenhouse gases; they perceived such a change to be relatively minor. This is not the case. For instance, it has been suggested that the melting of the polar ice caps, or conversely the initiation of a new ice age, could be triggered by a mean global temperature change of only a few degrees Celsius. As an example, from the temperature low of the last glacial period (approximately 18,000 years ago) to the temperature high (perhaps 7,000 years ago) of the warm "interglacial" period we are living in today, the mean temperature of the ocean rose only 2°C and the mean global temperature rose only 6°C. The increase in sea level brought about by this last ice melting episode is estimated at approximately 100 metres (328 feet) -- further warming and melting of polar ice masses could inundate coastal areas in the future. The last sea level rise occurred gradually, but this is not expected to be so in the case of the greenhouse effect. In fact, a sea-level rise of at least 30 centimetres, but possibly as high as 1.4 metres, is expected by the middle of the next century. This could inundate low-lying coastal lands and islands, and reduce coastal water supplies by increased salt water intrusion.

Scientists do not know exactly what a warmer climatic regime would be like. It is felt that a rise in temperature of 3.5°C to 4.2°C would probably result in a global average increase in precipitation, due to

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an increase in evaporation, of 7 to 11%. Distribution of these effects will probably be variable. In any event, changing the length of the growing season and altering traditional precipitation patterns would almost certainly disrupt established agricultural practices. More specifically, warming is expected to be two to three times more pronounced in high latitudes than the global average. Different studies suggest that mid-latitude continental interiors would experience a decrease in precipitation and an increase in evaporation with the warmer temperature, exacerbating already emerging problems of water supply. Such regions include the major grain-producing areas of the world including those of Canada and the U.S.A. Increased precipitation is expected in tropical and sub-tropical latitudes, and the frequency of tropical cyclones may increase and storm tracks may change with devastating impacts on coastal areas and islands by floods and storm surges.

F. Conclusion

The changes in the earth's atmosphere that are occurring at an unprecedented rate, coupled with the effects of rapid population growth in many regions, represent a major threat to international security. This was the major conclusion of the "World Conference on the Changing Atmosphere: Implications for Global Security," held in Toronto, Canada 27-30 June 1988. The need for international cooperation is paramount, and the Conference, with representatives from 46 countries, called upon governments to work urgently towards an Action Plan for the Protection of the Atmosphere. This Plan should include an international framework convention, and should encourage other standard-setting agreements and national legislation to provide for the protection of the global environment.

There no longer seems to be any doubt about the grave consequences to humankind if global policies, in particular energy policies, are not modified to curtail the greenhouse effect.

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PARLIAMENTARY ACTION

On 15 May 1981, the Special Committee on Alternative Energy and Oil Substitution tabled its final report, "Energy Alternatives", in the House of Commons. In its report the Committee proposed seven criteria for guiding energy development. Environmental concern was one of these. In the words of the report:

> Two of today's most disturbing environmental problems are acid rain and the accumulation of carbon dioxide in the atmosphere, and both of these phenomena result primarily from the combustion of fossil fuels. Thus environmental concern has been a major factor in causing the Committee to believe that a new energy system in Canada should be one which is not based principally upon the combustion of hydrocarbons.

CHRONOLOGY

1958 - Dr. Charles Keeling began monitoring the concentration of carbon dioxide in the atmosphere at a station on Mauna Loa in Hawaii.

February 1979 - The World Climate Conference, sponsored by the World Meteorological Organization, was held at Geneva, Switzerland. The conference emphasized the importance of climatic research and called for further study of the CO_2 problem.

October 1983 - The U.S. Environmental Protection Agency released a report warning that the climatic effects of atmospheric CO_2 accumulation would become apparent in the 1990s. The U.S. National Academy of Sciences issued a report on climatic change which foresaw a somewhat similar climatic alteration in the long term but viewed the situation with less apprehension.

25 September 1984 - An Ottawa symposium on "Global Change", sponsored by the International Council of Scientific Unions, discussed a proposal to establish an International Geosphere-Biosphere Program "to assess trends in natural and anthropogenic global change anticipated for the next 50-100 years."

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16 May 1986 - Documentation revealed that since the early 1970s temporary reductions of up to 50% in the ozone layer over the Antarctic in the month of October had occurred. CFCs were implicated as a contributor to this problem, as well as being trace gases involved in the greenhouse effect.

September 1987 - The Montreal Protocol was signed by 24 nations. It will come into force in January 1989 so long as it is ratified by at least 11 signatories that together represent at least two-thirds of the global consumption of "controlled substances," five CFCs and three halons.

27-30 June 1988 - The "World Conference on the Changing Atmosphere: Implications for Global Change" (Toronto, Canada) brought together scientists and policy-makers from 46 countries as a first step towards an international convention for the protection of the atmosphere.

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